A 'COLOR ILLUSION.'[1]

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In "Studies from the Yale Psychological Laboratory," Volume VI, 1898, there is an article entitled "A Color Illusion" by Professor George Trumbull Ladd. In it reference is made to a colored diagram, called an "example of Stilling's Charts," used for testing color blindness. The chart consists of a pale green background, 36 mm. by 44 mm., which is divided into squares of 1.8 mm., by white lines 0.4 mm. in width. On this background a red letter E, 21 mm. by 34 mm. is constructed out of similar red squares. It was noticed that when this figure was observed with a fixed gaze for a few seconds, some or all of the squares disappeared, and were replaced by green squares like those of the background.

When it was found that the illusion was not dependent upon the white division lines, a series of experiments was devised by Dr. E. W. Scripture to test the effects of varying the color of the background—or "substituting color"—while retaining the same red as the "disappearing color," without dividing either background or strip into squares. A set of Milton-Bradley colored papers was used, and out of these, sheets, 20 cm. by 30 cm., were cut for backgrounds, while small strips, 1 cm. by 20 cm., were cut, ready to lay on the backgrounds. To make the experiment, a background of a desired color was fastened to a board by tacks, and a colored strip was fixed on it by a pin; the whole was then observed at a distance of about 3 m. Although the results varied somewhat with different observers, yet "they remained fairly constant of the same order." The results obtained by a standard red strip, fixated on various backgrounds, may be divided, says the author, into two classes. With certain backgrounds—green, blue-green, violet, blue and black—the illusion of disappearance and substitution takes place quickly and suddenly. With other backgrounds—yellow, orange, light gray, white, light blue, light green and a light reddish violet—the substitution takes place with great difficulty, or not at all. If the same experiment is made with an orange strip, the illusion comes with green, dark violet, dark blue or black blackgrounds, only after persistent trying. On the red

[1] From the Psychological Laboratory of Cornell University.

strip the color darkens, but on the orange strip it lightens, and the background color seems to encroach on the strip from both sides until (where the strip does not disappear entirely) it is but a narrow "line of sunlight."

By way of general explanation, fatigue, in the sense of the Young-Helmholtz theory, is suggested. The colored strip is said to fatigue the eye and thus to create a temporary blind spot, which is filled in by the color of the background as the permanent blind spot is filled from surrounding retinal areas. The explanation is admitted to be unsatisfactory, for (1) dark strips seldom disappear on light grounds, and (2) orange grew brighter and lighter, instead of darker, before disappearing.

Aside from the general difficulties which the principle of fatigue or exhaustion encounters (the rise of negative after-images after a very short exposure, while the eye is, nevertheless, able to function throughout the day), there are here two special difficulties. (1) Why should a limited retinal area succumb while other areas, which are similarly exposed to stimulation, are unaffected? In the second place, (2) fatigue, as generally conceived, does not produce an entire absence of visual sensations, but only a change. Exhaustion to red, for example, produces some other color than red, depending on conditions of stimulation. The exhaustion of the "red-fibre" does not straightway throw the visual apparatus out of function; it only changes the reaction of the apparatus.

Since the explanation is avowedly inadequate, and since the phenomena described have considerable interest in connection with theories of color-vision, at large, it has seemed worth while to repeat the Yale experiments with some modifications.

The experiments which are described below were carried out in the Cornell Laboratory during the academic year 1899-1900.

Sheets of colored paper (Milton-Bradley), 10 cm. by 15 cm., were cut out for backgrounds, and strips, 0.5 cm. by 10 cm., were cut out to be placed upon these backgrounds. A pin with a small, round, black head fastened the strip vertically to the middle of the background, and also fastened the background to a black upright screen, which was placed 1.5 m. from the observer. An uniform light fell on the strip, background and screen from behind the observer, so that no shadows or reflections were produced. A series of eighteen colors were used as backgrounds, while only the six 'standard' colors were used for strips. After a preparatory "Ready," the signal "Now" was given, a stop-watch was started, and the observer fixated the head of the pin. If the strip disappeared, and complete substitution took place, the observer indicated the fact, and the time of disappearance was noted. If it did not disappear, the fixation was continued for two and a half minutes. The intro-

spection was then written, and the eyes were rested until all after-images had disappeared, before proceeding with the next combination; the time allowed for rest being at least three and a half minutes. The colors used were:

Violet red (V. R.). Rather dull and dark.
Red (R.). Dark and saturated.
Orange red (O. R.). Vivid, brighter than R., saturated.
Red orange (R. O.). Brighter than red, very saturated.
Orange (O.). Very bright and vivid, strong.
Yellow orange (Y. O.). Bright, unsaturated.
Orange yellow (O. Y.). Bright, darker than yellow, unsaturated.
Yellow (Y.). Bright, very little saturated.
Green yellow (G. Y.). Vivid, bright, thin.
Yellow green (Y. G.). Bright, well saturated.
Green (G.). Moderately bright, not very saturated.
Blue green (B. G.). Bright, not very saturated.
Green blue (G. B.). Rather dark, not very saturated.
Blue (B.). Well saturated, darker than green blue.
Violet blue (V. B.). Dark, well saturated.
Blue violet (B. V.). Dark, moderately saturated.
Violet (V.). Rather light, not highly saturated.
Red violet (R. V.). Rather light, not very saturated.

The observers were Dr. Lane (L.), Miss Winger (W.), Miss L. Hempstead (H.), and the writer (M.), all students in the Psychological Department.

The first fact investigated was the disappearance of the strip. Out of 408 tests—each strip with all the different backgrounds repeated with the four observers (6x17x4)—there were 93 'disappearances.' Of these, 37 were reported by H, and the other 56 were distributed almost equally among the other observers (19, 20, 17). The number of disappearances of the strips, running through the spectrum from red to violet, was as follows: 14, 18, 8, 13, 23, 17; blue disappearing most often and yellow least often. There is a good deal of variability in the backgrounds upon which the strips were lost. Only once did all four observers report a disappearance with the same combination of strip and background. This was with *B.* on *V. B.* There were 10 concurrent disappearances with 3 observers: *V.* on *G. B.*, *B. V.* and *R. V.*; *B.* on *V. R.*; *G.* on *R. O.*; *O.* on *R. O.*, *Y. G.* and *G.*; *R.* on *V. R.* and *B. V.* Some disappearances occurred with every background: *R.*, *O. Y.* and *Y.* gave the fewest (2 each), and *R. O.* the most (10). When one remembers the heterogeneous nature of the papers, variations in brightness, color tone and saturation, and mixture of pigments, one can hardly wonder at the apparent confusion in the results. It is worth noting, however, that in the 11 concurrences which we have mentioned there exists in each case a likeness between the strip and the ground either in (1) color tone, (2) brightness, (3) lack of saturation or (4) in two or three of these moments at the same time.

Much more important than these numerical results (considering the unsatisfactory character of the estimate) is the introspective account of the experiments. Introspection brought out the following facts.

A. At the first glance the contrast, both in color and brightness, was greatest. This contrast was at times very striking.

B. Quite soon, however, the strip and ground began to lose saturation, and to approximate each other in brightness, until, in cases of complete disappearance, the brightness of the strip and of the ground were the same. Although both colors yielded to each other more or less, the strip yielded the most and was merged in the ground.

C. After the approximation in brightness, but before its disappearance, the strip was covered by a 'veil' of the background color, through which the color and form of the strip could be seen in a greater or less degree. Sometimes the color of the strip spread over the background to a small extent; the veiling of the strip occurred, however, in almost every case.

D. The strip then lost its identity, going entirely into the background which had diminished in saturation and in brightness of tone.

Beside this general course in the visual sensations, a number of special points were noted. (1) In 82 tests the strip either approximated the color of the background, or became merely a line of brightness with definite or indefinite outlines.

(2) In 44 tests the strip narrowed down to a small area directly around the pin head. At times, both color and form remained here; again, only color; and still again, just brightness remained.

(3) In 54 combinations the one end disappeared entirely, almost to the center. At times the one end would go and then the other, but never both at the same time, the upper end reappearing before the lower one went and *vice versa*.

(4) The background was surrounded at times by a halo of the complementary color.

(5) In 22 cases, the background or the strip lost in saturation, and approximated the other in brightness; it became a "peculiar, luminous gray;" and, finally, changing over, acquired either the color complementary to the original color of (a) the background or of (b) the strip, or (c) some other color.

Again, (6), in some instances, the strip and background simply lost saturation, and became grayer.

CONCLUSIONS.

Since the invocation of the principle of exhaustion or fatigue has been found inadequate, we propose to interpret the facts which have now been collected in the light of a rival theory

of visual sensations,—the theory of Hering. It is very evident that at least some of the phenomena which we have called attention to are intimately connected with Local Adaptation and Contrast. Suppose that we take Hering's account of these two groups of facts, as it is given in the "Zur Lehre vom Lichtsinne," and attempt to apply his explanations to the results before us.[1]

First in regard to our general results.

A. The increase in color and brightness differences at the very first is a matter of simultaneous contrast (pp. 42 and 129).[2] This is due to the indirect effects of stimulation.

B. The approximation in brightness and the decrease in saturation is due to *local adaptation*. As the effect of adaptation, all brightnesses tend toward a medium gray, and all colors tend toward their complementaries, passing through gray, the point of minimal saturation (pp. 131-134).

C. The veil of the background color which spreads over the strip is caused by simultaneous light induction.

This is, again, an illustration of the fact that the retina is an unit and functions as a whole. As a consequence, the effect of stimulation is not limited to the region directly affected but extends to neighboring portions of the organs (indirect stimulation). It is to be noted that the effect of simultaneous induction is reciprocal; the color of the strip spreads to the ground, and that of the ground to the strip (pp. 19, 29, 129).

D. This is simply a later stage in the processes already described. Adaptation continues to affect the colors of the ground and of the strip. There seems, however, to be a slower adaptation for the more extensive ground (we know that the color of a small patch is very unstable; *cf.* pp. 131-2) and hence a preponderance in the successive color induction from this to the strip. A very important point in this connection is the fact that the background is only *relatively* stable; it undergoes change as surely as does the smaller strip. This fact gives the key to the whole phenomenon. It seems to have been overlooked by Professor Ladd. To test the effect of steady fixation upon the background, the whole series of "substituting colors" was used without the strips, *i. e.*, they were simply fixated upon the black screen. Out of the 72 tests (18x4), 19 gave gray (total loss of saturation), 41 gave a partial loss of saturation, 8 gave the complementary color and 4 some other color. *In no single case did the ground retain its original quality.* The sudden "vanishing" of the strip, which occurs at times, is probably

[1] A good general account of the phenomena of Contrast and Adaptation and their explanation may be found in H. Ebbinghaus, *Grundzüge der Psychologie*, I, 1897, pp. 217-229, 245-263.

[2] The references are to the *Lichtsinn*.

due to fluctuation of attention at the point where differences of the strip and ground are almost eliminated.

The more special facts related above do not call for extended explanation. The cases in (1) are made intelligible by the smaller area of the strip as compared with the area of the background. Here extension is a factor in the determination of the qualitative effect, as in temperature it influences quantity (intensity). The instability of a small color-stimulus is more easily demonstrable if a liminal extent of color is taken. The exact value of the extensive attribute of visual sensations needs working out. The peculiarities of (2) and (3) are doubtless to be referred to attention to the black fixation point, and to differences in distribution of the visual substances. The halo in (4) is another instance of simultaneous induction (p. 129). We have already considered the conditions operating in (5). For the physiological processes in this case see pp. 126 ff.

It is worth noting that whenever the strip became complementarily colored it was a yellow or a violet strip,—a poorly saturated stimulus,—one, therefore, that stands near gray, and hence near its complementary. Where some color other than the complementary followed the loss of saturation, it was the color which would have been produced by the mixture of the strip color, or of its complementary, with the induced color from the ground; *B.* on *Y. O.* gave *G. Y.* three different times (*B.*+ *Y. O.*=*G. Y.*),[1] and *V.* on *O. Y.* gave *Y.* (comp. of *V.*=*G. Y.*, *G. Y.*+*O. Y.*=*Y.*). Again, in the case of the grounds, it was the yellows and the violet which went over to the complementary color; both with the strip-background experiments and with the backgrounds by themselves. All these things we should expect to follow local adaptation and induction. Point (6) represents the first stage of adaptation.

Our observers noted the apparent lightening of the bright colors, orange, yellow and green, and darkening of the red and blue, with decreased saturation. A similar fact was mentioned in the Yale experiments. We are very strongly inclined to regard this as a misinterpretation of the facts. The absolute brightness of colors is difficult to determine. We underestimate the large brightness differences in the spectrum. These differences come out sharply when the color-tone is reduced or eliminated through the process of adaptation. A red is so rich, so saturated, so "taking," that we do not realize its small brightness valence; hence, when it begins to grow gray, it seems gradually to darken. One can easily convince oneself of this fact, by fixating monocularly for some time a good red, meanwhile

[1] Blue was a saturated color, and evidently did not quite reach the gray stage.

looking for an instant, from time to time, at the same stimulus with the unused eye alone. In this way one can bring the dulled and the original red, practically, side by side and easily compare them in brightness as well as in saturation. This method will also quickly bring the conviction that the phenomenon here in question is not a 'strip-phenomenon,' but rather that it embraces the whole field of visual sensation. The strip is no more truly affected than the background, and the background than its surroundings; its changes are more striking because it happens to be smaller, and because it lies in the focus of the attention. The phenomenon is no more an 'illusion' than is any change in visual sensation which is a result of the temporal course of stimulation.